Cloud Simulations and Retrieved Surface Temperature Biases

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Simulation System Design Philosophy

- Provides a global ensemble of states
- Contains local variability (within retrieval sets), addresses impact of algorithm assumptions
- Is weighted towards retrievable states
  - testing in intractable conditions is not practical use of resources
  - develop algorithms for identifying “hopeless cases”, e.g. cloud covered, or little variability
- Aid for validation and error assessment

Cloud Fraction Simulation

- Contains 2 or fewer opaque cloud layers
- Has an applied 30% random (Gaussian) perturbation to forecast cloud fraction to simulate local variability

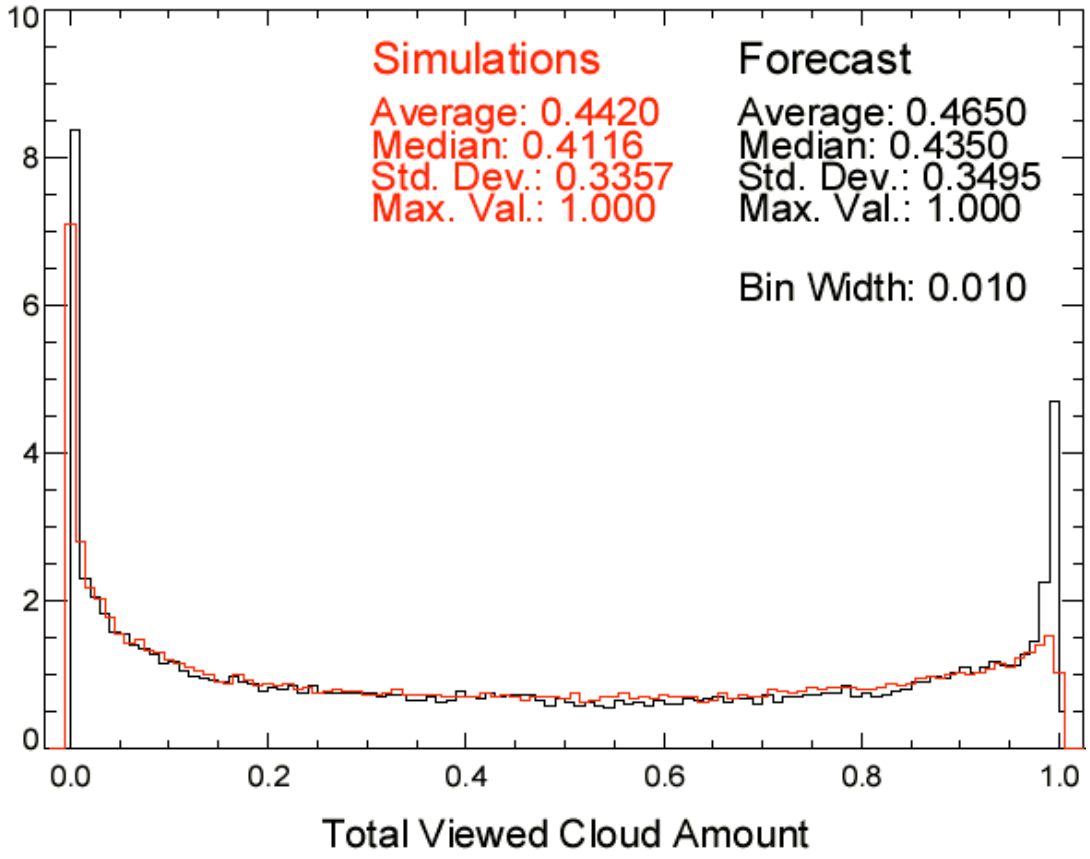
$$f_i^{\{u\,l\}} = f_{\mathrm{m}}^{\{u\,l\}}\left(1 + 0.3 n_i\right)$$

- Clouds are spatially uncorrelated in upper and lower layers
- Clouds are small compared to AIRS footprint

$$f_{\mathrm{v}\,i}^{\{u\,l\}} = \left(1 - f_i^u\right) f_i^l$$

Total Cloud Cover Density

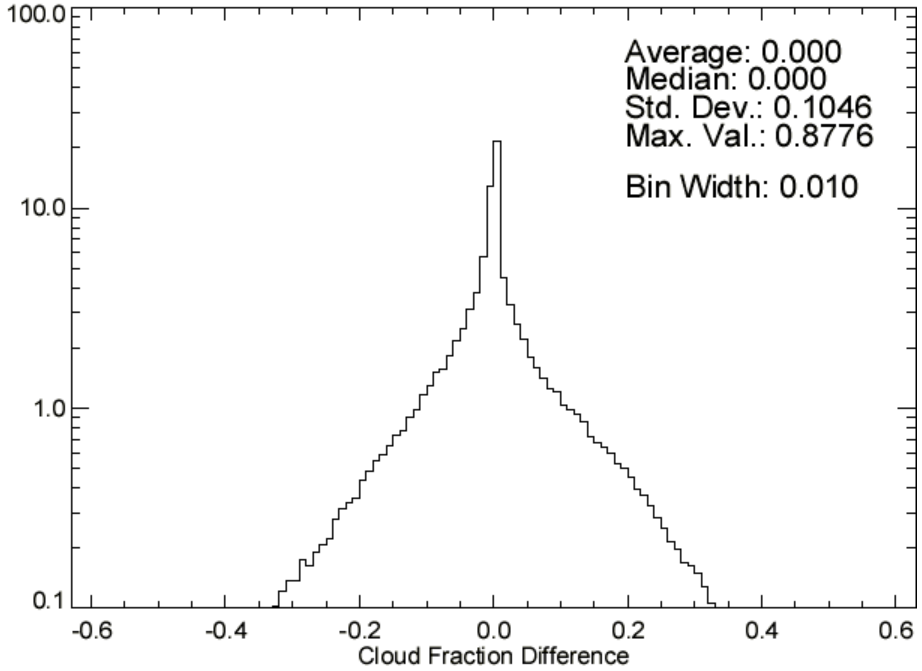
- Impact of local variability model on global statistics
  - Simulated cloud amount is reduced slightly
  - probability of full overcast conditions is reduced by factor of 2
  - near clear conditions are slightly reduced



Cloud Cover Local Variability

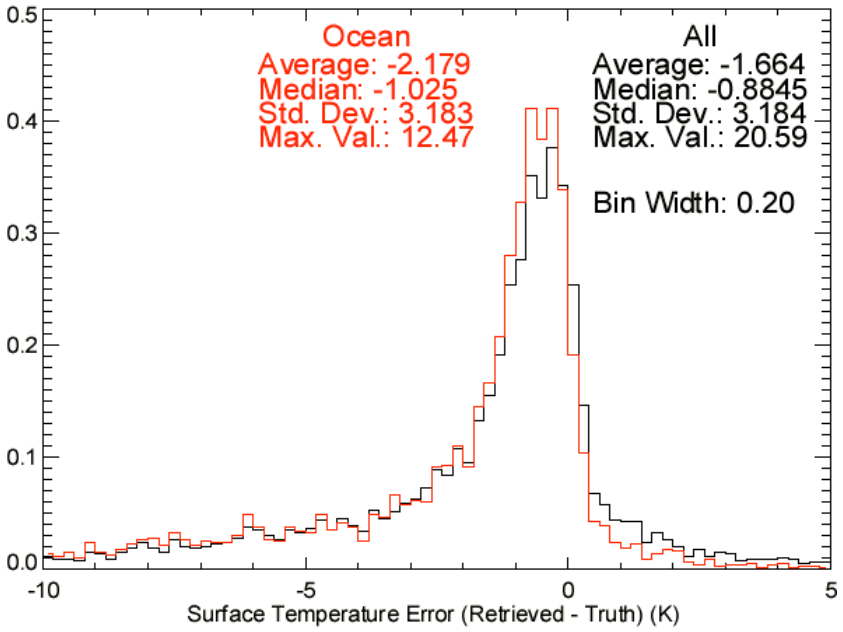
- Differences from mean within each retrieval set
- Gaussian distribution
  - 10% standard deviation
  - departs from Gaussian behavior at differences greater than 0.1

    (constraint on maximum fraction)



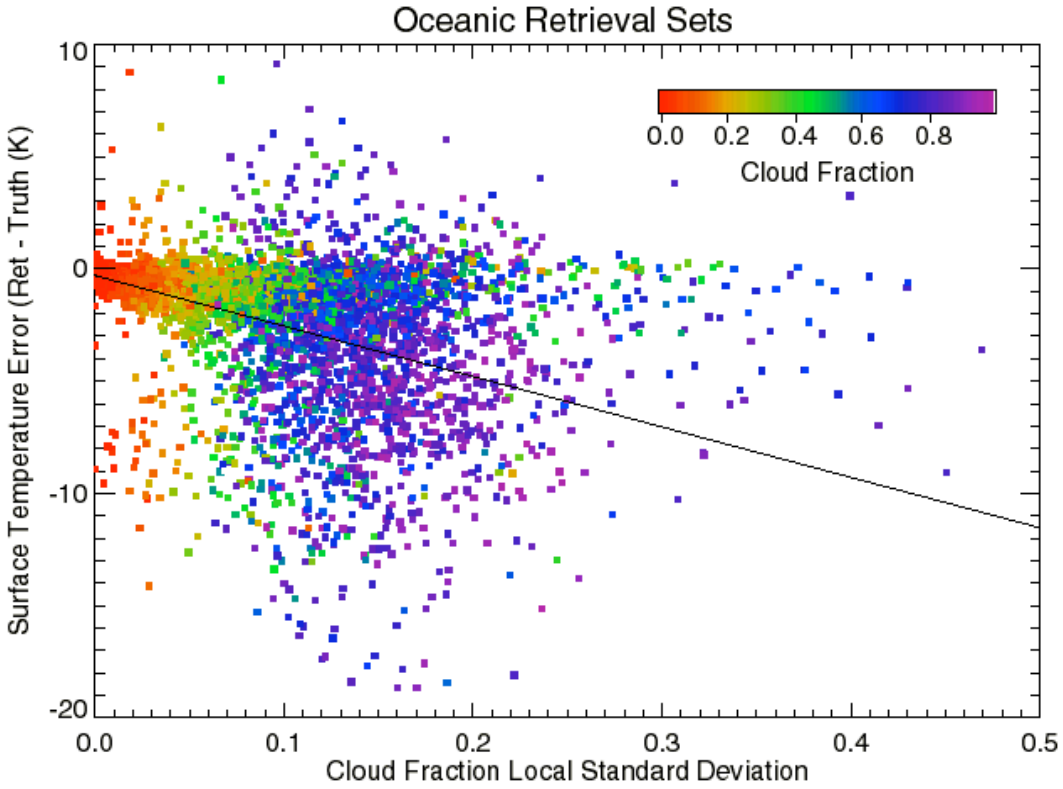
Retrieved Surface Temperature Errors

- Retrieved biased 1K cold
  - Comparable over land or ocean
- Accuracy (standard deviation) 3K



Surface Temperature Error and Cloud Fraction Variability

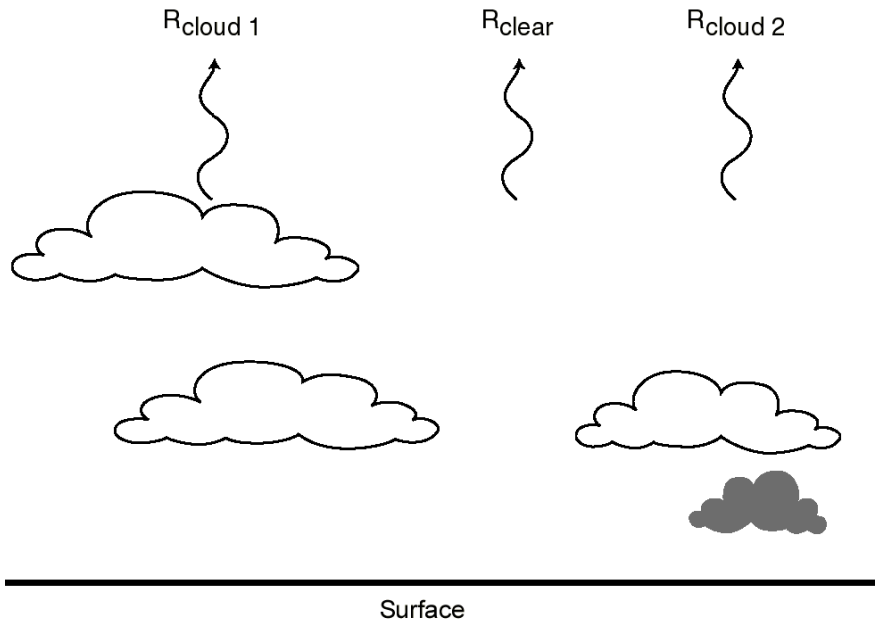
- Local variability and mean cloud fraction are highly correlated
- A few anomalous points
  - low cloud amount, nominal variability, but large errors



Surface Temperature Bias Observations

- Generally bias is small when cloud fraction is less than 20%
- Error around -0.4K in the limit of zero cloud fraction
- Error increases with cloud fraction faster than expected
- Anomalous points (large errors, moderate cloud fractions)
- Cloud clearing problem is singular for multiple cloud layers when fractions are correlated
- Correlation may be two large in simulations
  - opaque clouds increases correlation
  - variability linearly related to mean cloud amount

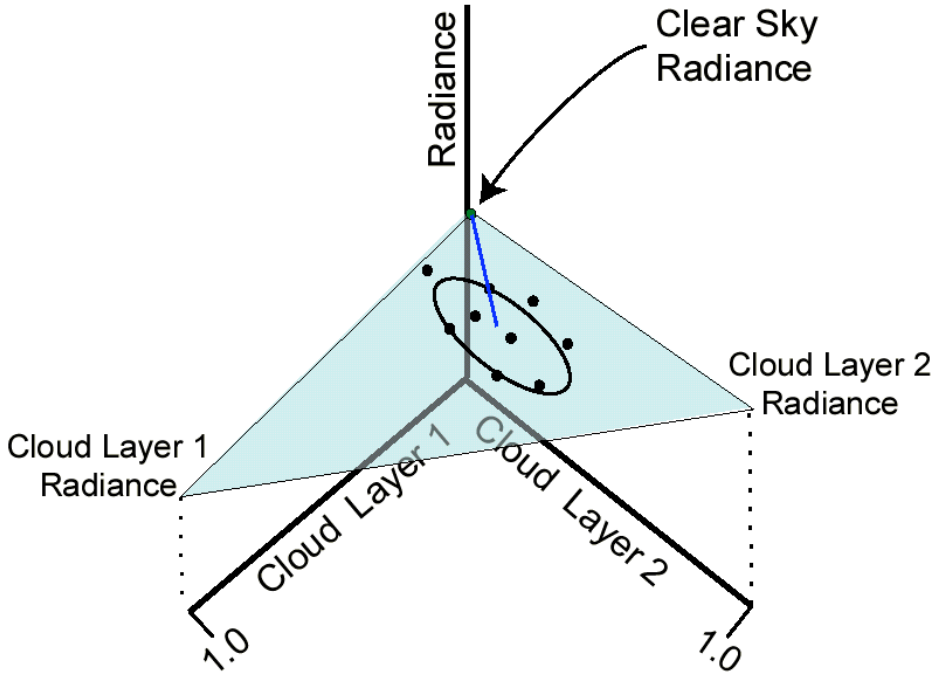
Cloud Clearing Algorithm



$$R_i = f_i^1 R_1 + f_i^2 R_2 + \left(1 - \left(f_i^1 + f_i^2\right)\right) R_S$$

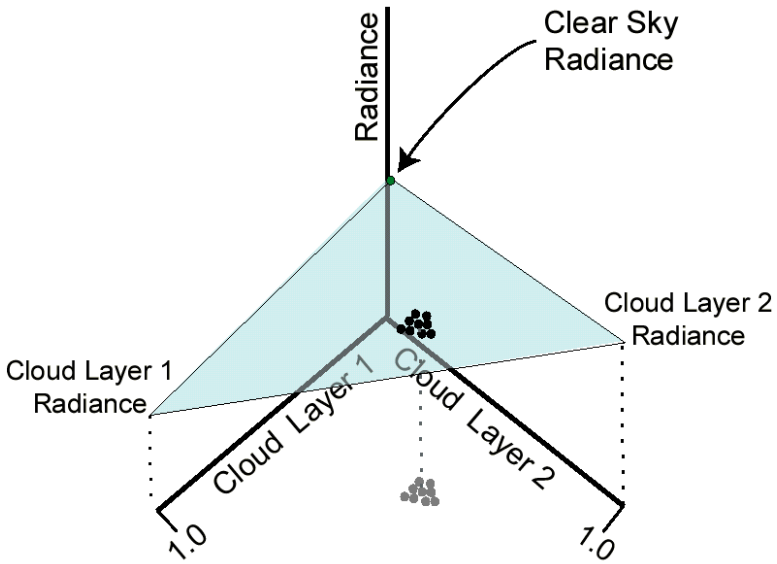
Cloud Clearing
Geometric Perspective

- Radiance is area-weighted linear combination of radiances from cloud-free surface and viewed cloud layers
- Fit plane through nine point and determine where it intersects “z” axis (cloud free)
- Plane is defined by three points not on the same line

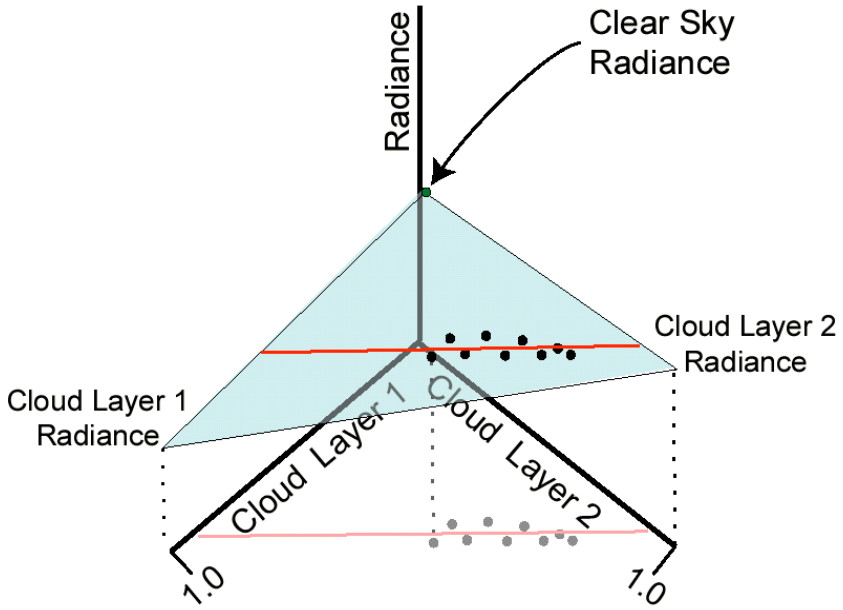


Cloud Clearing
Singular Conditions

- Points are clustered

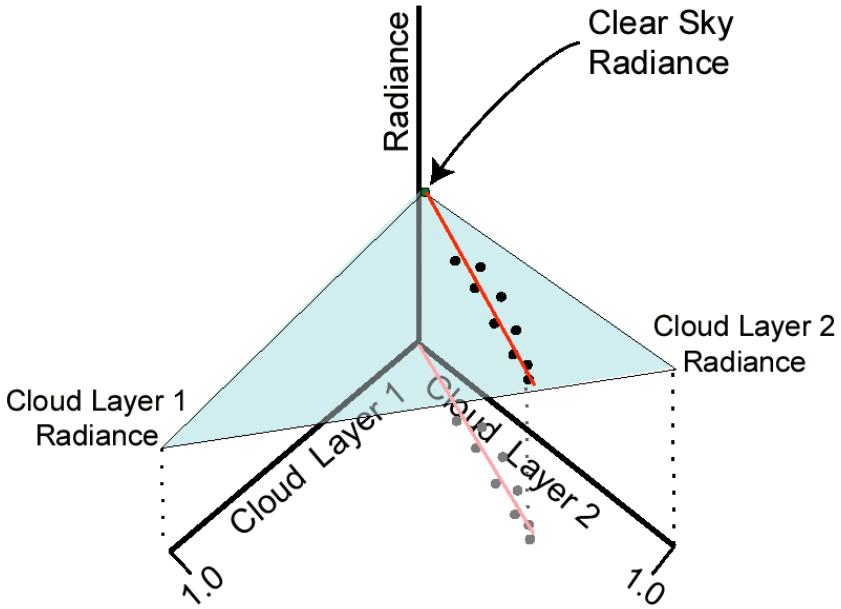


- Points are correlated



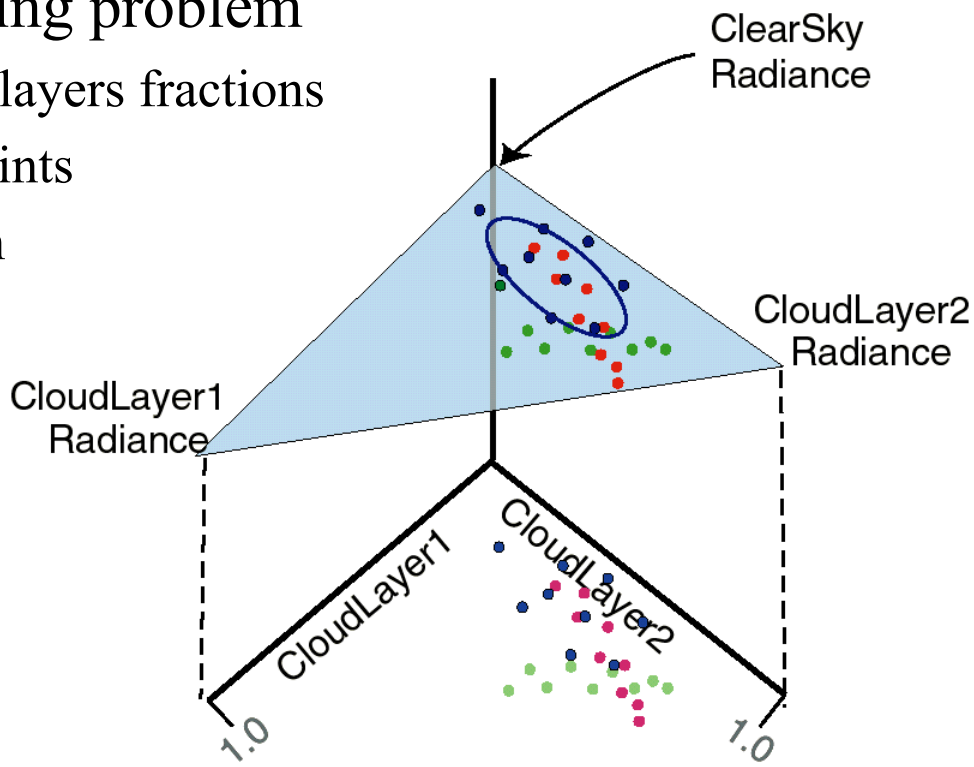
Cloud Clearing
Singular Conditions (cont)

- Non singular if points are correlated, but line includes clear sky



Cloud Clearing Diagnostics

- Define diagnostics in simulations that characterize tractability of cloud clearing problem
  - correlation between cloud layers fractions
  - error in fitting plane to points and extrapolating to origin



Correlation Diagnostics

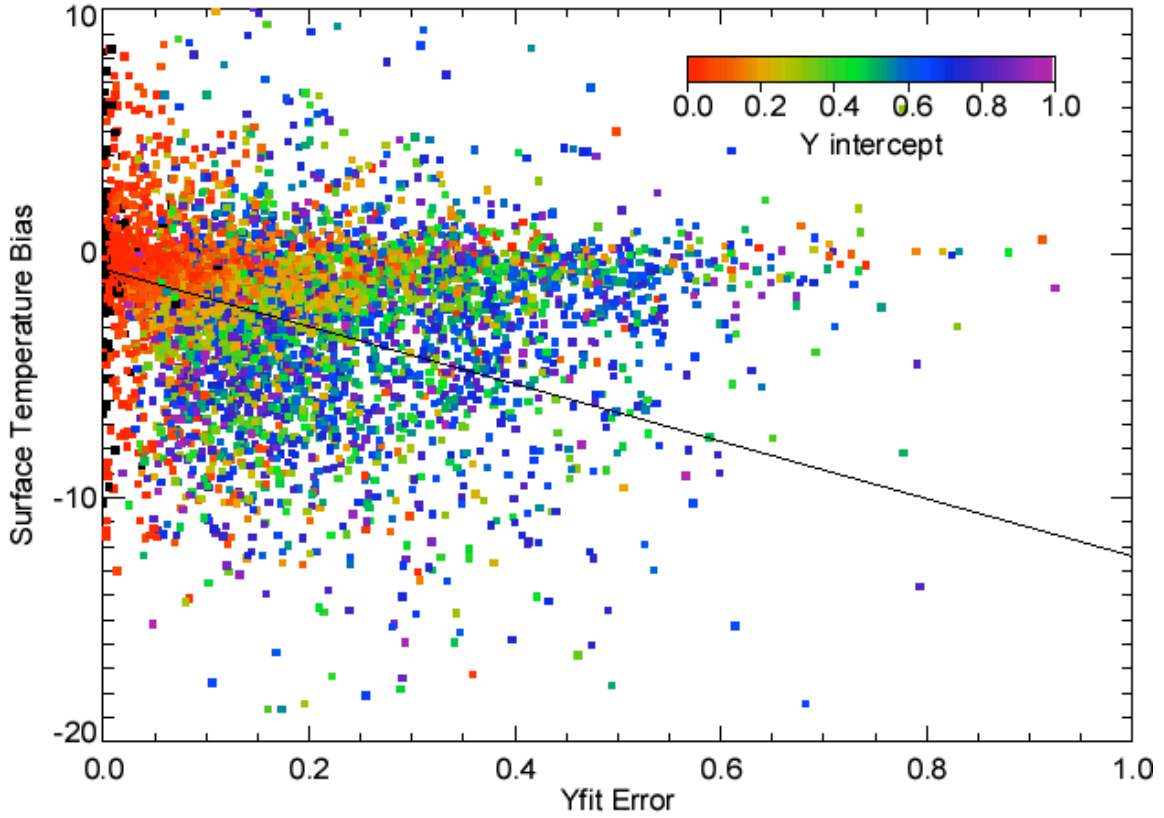
- Regress layer fraction with least variability against layer fraction with most variability

$$f_i^{\{1 \text{ or } 2\}} = f_0^{\{1 \text{ or } 2\}} + s f_i^{\{2 \text{ or } 1\}}$$

- Diagnostics
  - error in fit $\sqrt{\square^2}$ (measure of correlation)
  - error in slope $\square_s$ (measure of correlation)
  - y intercept $f_0^{\{1,2\}}$ (residual clouds)

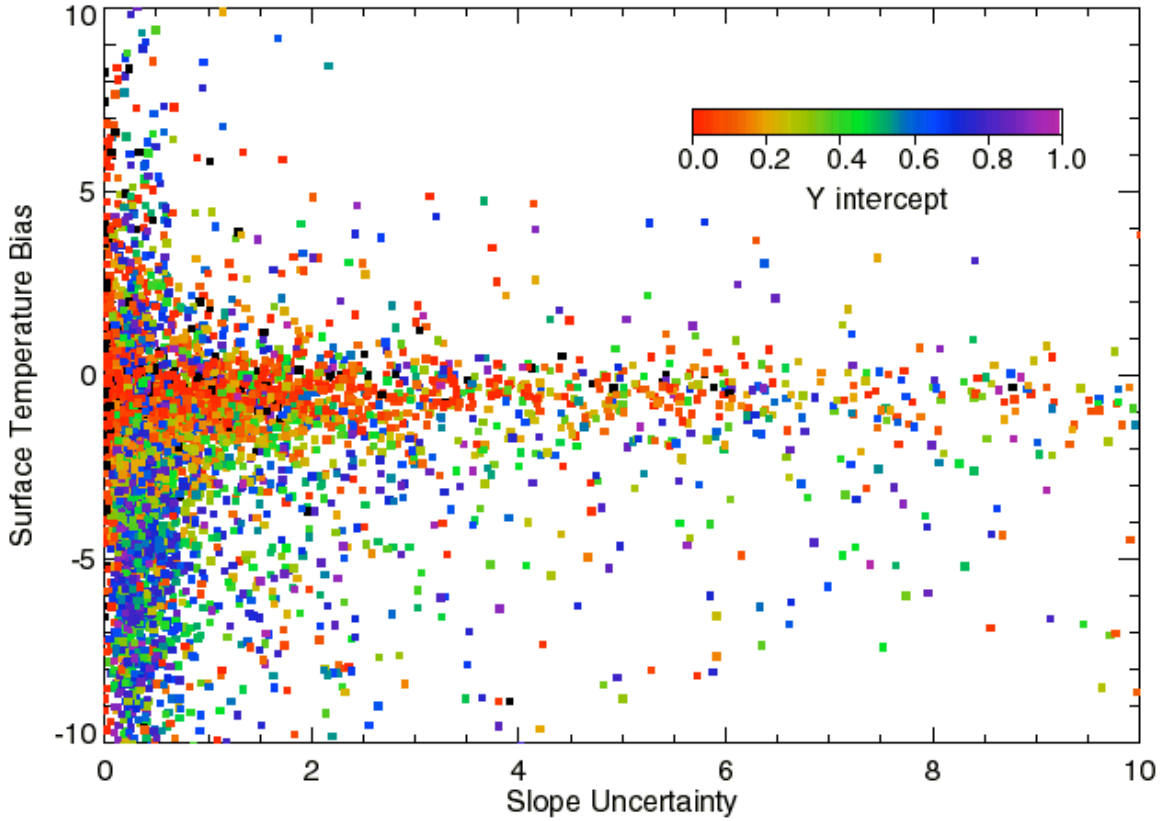
Error in Fit to Cloud Layer Amount

- Weak increase in surface temperature error with fit error
- Correlation between error in fit and surface temperature error is poor



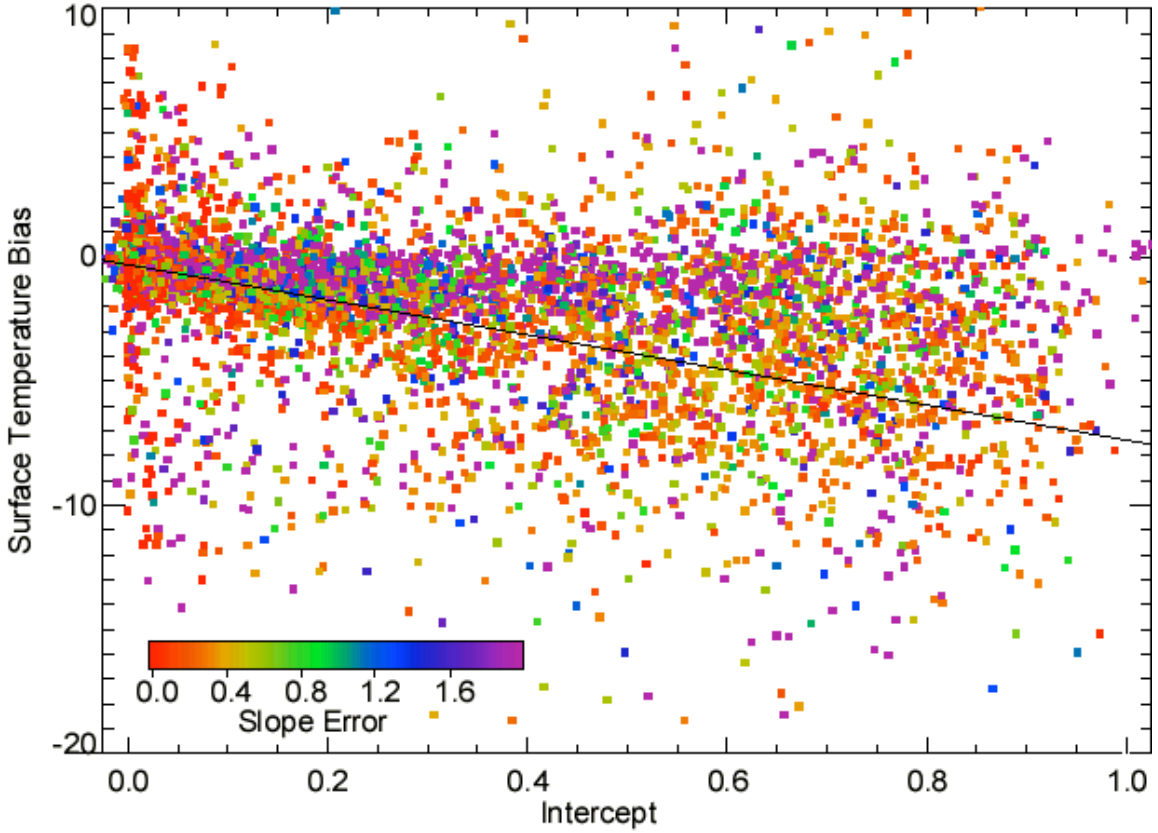
Error in Estimate of Slope

- Surface temperature error is
  - large when slope error is small (< 0.5) and y intercept is large (> 0.3)
  - small when slope error is larger than 3



Cloud Amount at Intercept

- Surface temperature error decreases with intercept, but
  - large scatter at small intercept with small slope error
  - large scatter at larger intercepts, uncorrelated with slope error

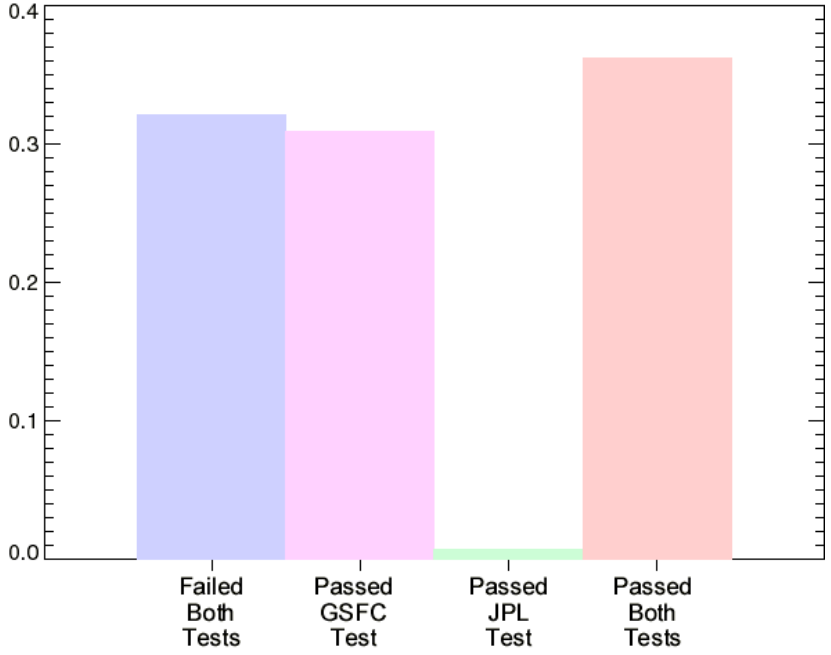


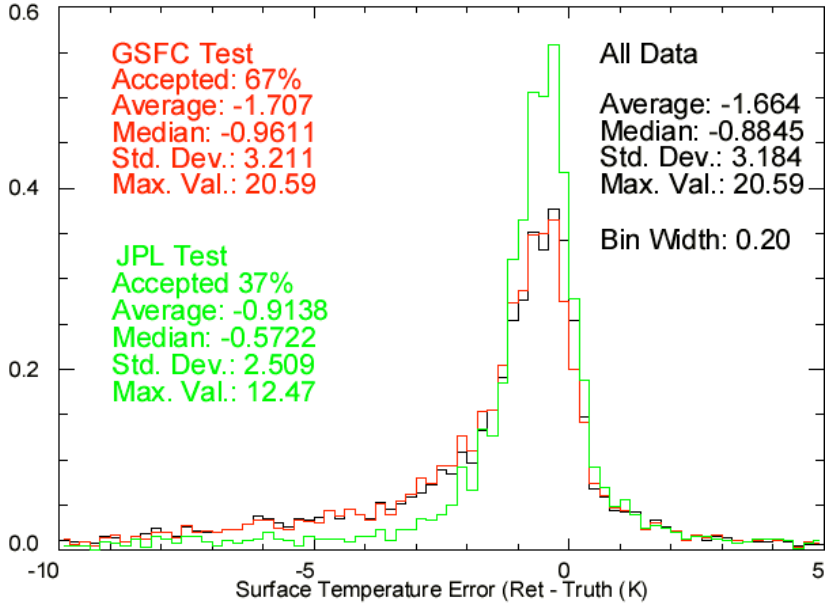
Comparison of Correlation Diagnostics

- Test conditions when cloud clearing is possible
  - GSFC test: $f_0 \square 0.02$ or $\sqrt{\square^2} \geq 0.1 f_0$

    statistics not improved
  - JPL test: $f_0 \square 0.1$ or $\square_s \geq 2$

    rejects too many "good" cases





Assessment of Correlation Diagnostics

- Surface temperature error not significantly improved in cases satisfying tests
- Possible explanations
  - tests are not effective indicators of cloud clearing problem
  - surface temperature bias is generally weakly associated with cloud clearing singularity

Plane Fitting Diagnostic

- Estimate error on clear sky radiances from regressing plane through points

$$\begin{vmatrix} R_1 \\ R_2 \\ \mathrm{M} \\ R_9 \end{vmatrix} = \begin{vmatrix} f_1^1 & f_1^2 & 1 \square \left(f_1^1 + f_1^2\right) \\ f_2^1 & f_1^2 & 1 \square \left(f_2^1 + f_2^2\right) \\ \mathrm{M} & \mathrm{M} & \mathrm{M} \\ f_9^1 & f_9^2 & 1 \square \left(f_9^1 + f_9^2\right) \end{vmatrix} \begin{vmatrix} R_{C1} \\ R_{C2} \\ R_S \end{vmatrix}$$

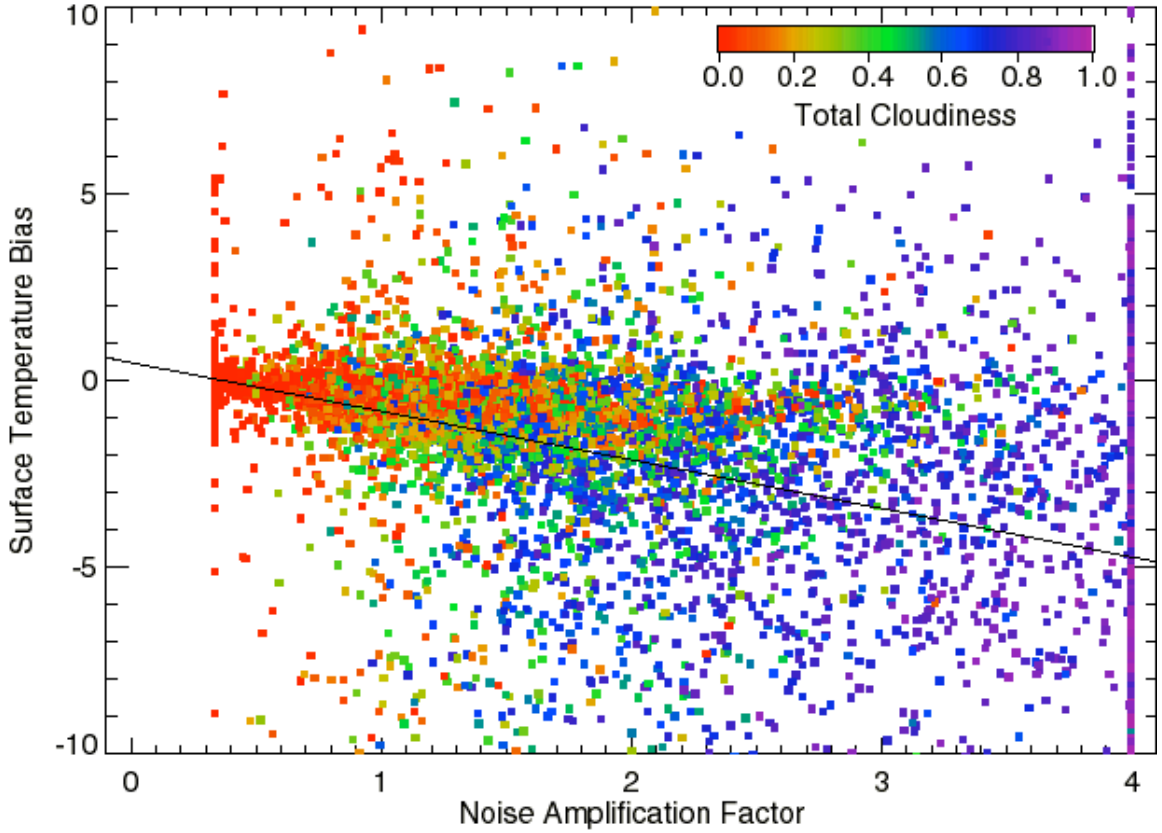
- Noise amplification factor (error estimate) is independent of radiances

$$\mathrm{NaF} = \square_{R_s} = \sqrt{\left(\mathbf{F}^{\mathrm{T}}\mathbf{F}\right)^{\square 1}\Big|_{R_s R_s}}$$

  - SVD required to obtain estimate

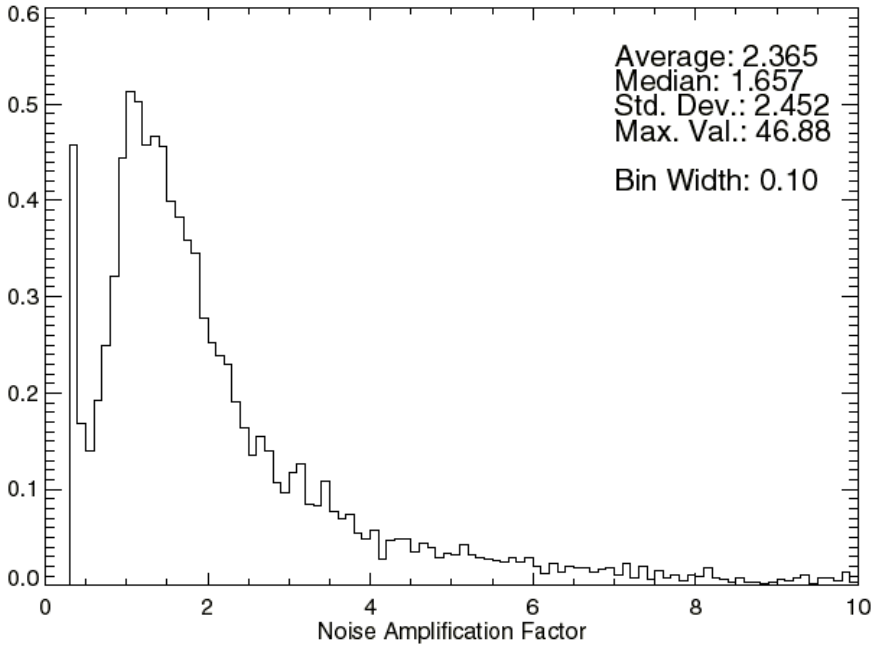
Noise Amplification Factor

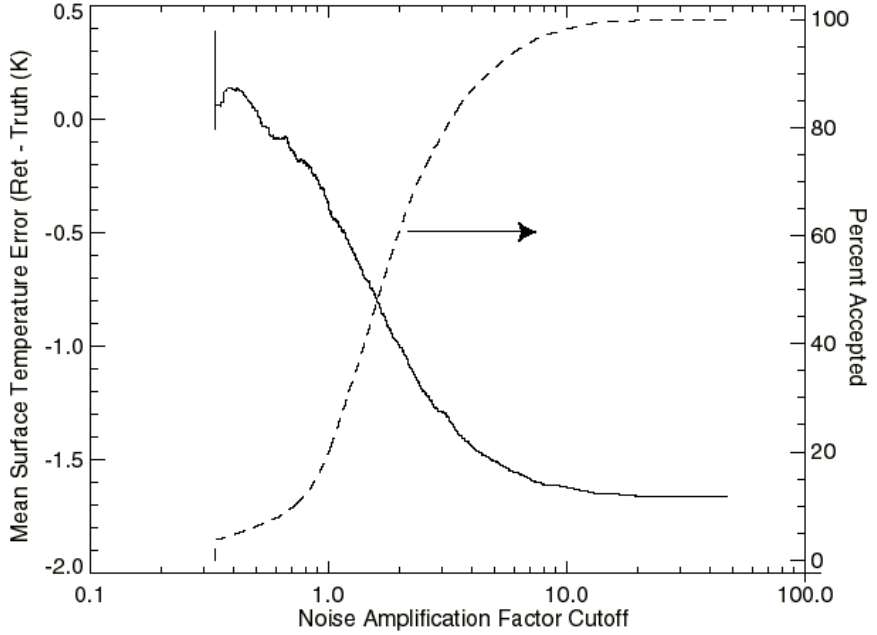
- Properties
  - minimum of 0.33 for cloudless retrieval sets
  - becomes large when plane is not constrained by cloud fractions



Cloud Amplification Factor (cont.)

- 60% of retrieval sets have NaF □ 2
- Mean surface temperature bias is □1.0K for retrieval sets with NaF □ 2





Cloud Simulations Updates

- Problems
  - sensitivity of cloud clearing to local variability
  - ad hoc local variability model
  - greater than 50% of retrieval sets have NaF greater 1.7
- Monte Carlo simulations have been used to identify potential cloud fraction models

Revised Cloud Fraction Model

- Randomize using uniform random variates (u)

$$f_i^{\{u\,l\}} = \frac{u_i^{\{u,l\}}}{\overline{u}^{\{u,l\}}} f_{\mathrm{m}}^{\{u\,l\}}$$

- Correct lower layer

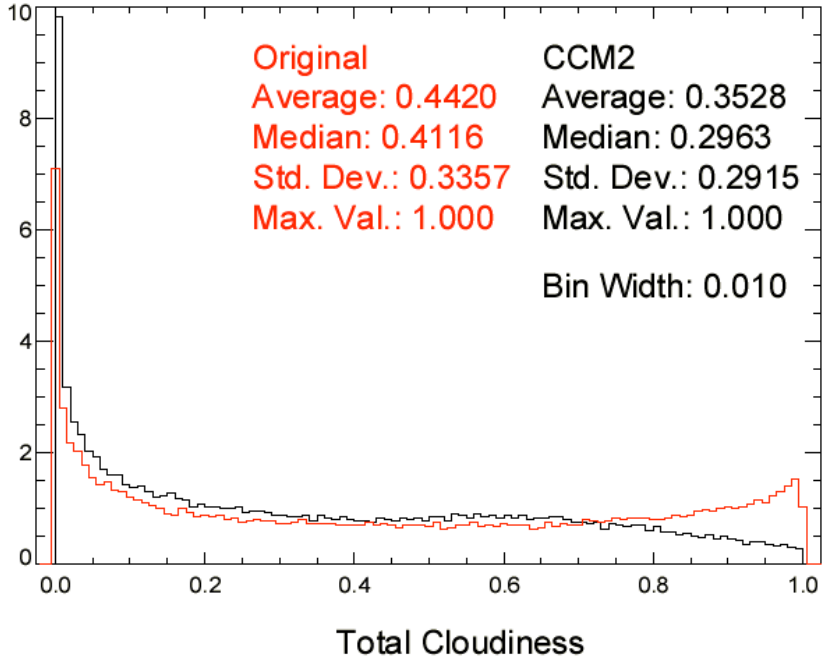
$$f_{\mathrm{v}\,i}^{\{u\,l\}} = \left(1 - f_{\mathrm{m}}^{u}\right) f_i^{l}$$

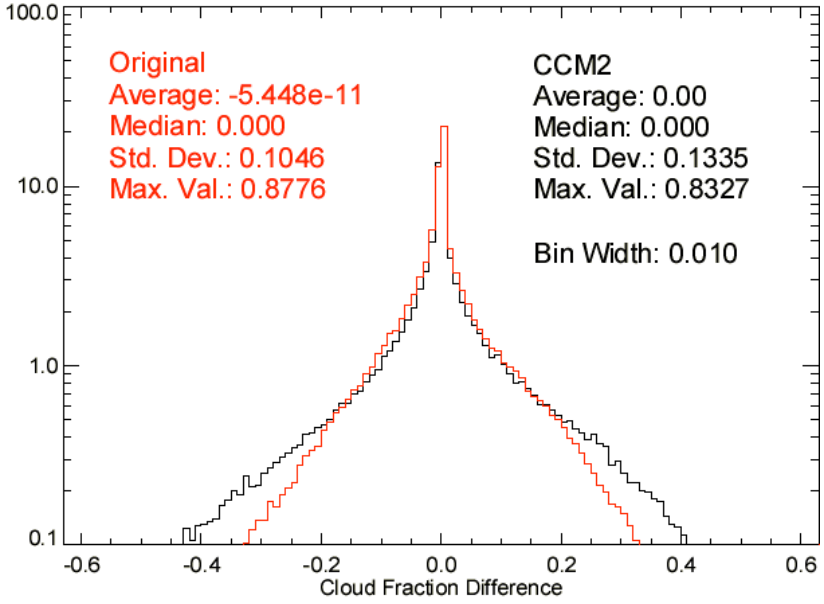
- Adjust lower layer when $f_{\mathrm{v}\,i}^{u} + f_{\mathrm{v}\,i}^{l} > 1$

$$f_{\mathrm{v}\,i}^{l} = f_{\mathrm{v}\,i}^{l}\, u_i$$

Revised Cloud Fraction Model Characteristics

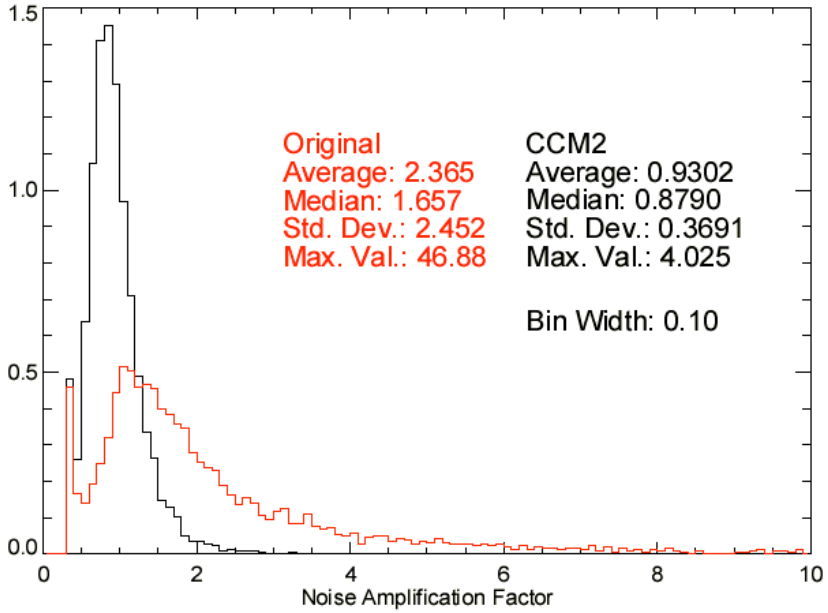
- Mean cloudiness reduced
- Local variability increased





Expected Error from CCM2

- Reduced NaF
  - 98% of retrieval states will have NaF < 2
- Global mean surface temperature error will be reduced from 1.7K to 1.0K



Conclusions

- Source of surface temperature bias has not been shown to arise solely from singular cloud clearing conditions, or
- Noise amplification factor may not diagnose singular conditions (it seems to)
  - if a diagnostic can be identified, correlative cloud data can be used to identify problematic conditions
- Simulations have identified a wider range of cloudy conditions where cloud clearing may be difficult
- Simplified test simulations are being implemented to identify sources of bias and validity of NaF or other diagnostics
- Verification of local cloud variability model would improve quality of error estimates from simulation

Cloud Clearing Test Cases

- Case 1: States for all footprints in retrieval set are identical, no cloud or noise (best case scenario)
  - identify whether surface temperature errors arise in the absence of noise, clouds or surface heterogeneity
- Case 2: case 1 with noise
  - differences with case 1 shows degradation from noise
- Case 3: case 2 with clouds
  - differences with case 2 shows degradation from clouds
  - identifies usefulness of NaF and other diagnostics
  - differences with nominal case (includes heterogeneity) addresses impact of cloud clearing assumptions.